## DETAILED DESCRIPTION

According to the embodiments described herein, a method and apparatus are described in which a plurality of r/c model vehicles can be powered by a single battery system. The battery system allows different number of serial and parallel cells to be quickly reconfigured to match the voltage and power requirements of the vehicle.

Battery cells currently come in four generic classes: Alkaline, Nickel-Cadmium (NiCd), Nickel-Metal-Hydride (NiMh), and Lithium. Additional classes (like zinc-air) will be added in the future for hobbyist uses. The Alkaline (which is the common household flashlight battery type) produces 1.5 volts nominally when new. It is rarely used in the hobbyist market because it is typically not rechargeable and thus very expensive to employ on a long-term basis. Both the NiCd and NiMh produce 1.2 volts per cell and are the dominant types today in the r/c market. They are rechargeable and can typically be re-used 200-500 times before they need to be replaced. They have a very low cost of long-term operation. Lithium (both the metal-ion type and the polymer type cells) produce 3.7 volts per cell and are quickly becoming the battery of choice for small airplanes, boats, and helicopters because it has a great weight to power ratio. This provides long vehicle operation duration. They are rechargeable approximately 200-300 times before needing replacement and the Lithium cells are currently about 50% more expensive than their equivalent power NiCd cells. However, the Lithium polymer cells typically weigh ½ to 1/3 as much as their NiCd counterparts and thus are very desirable in aircraft and water vehicles where reduced weight has high value.

Battery cells are typically connected in series to provide an operating voltage range between 4 to 30 volts. Most brushed electric motors used for propulsion operate with a range of 6.0 to 10.0 volts. Most r/c electronics systems can operate anywhere in the 3.7 to 12 volt range. Highly efficient "brushless" motors for propulsion typically need higher

voltages (9 to 30 volts). Fig.1 shows schematically how a typical brushed r/c model airplane would be configured for a battery system that provides 6 cells of NiMh. The 6 cells provide 7.2 volts to an Electronic Speed Controller (ESC) which provides a regulated voltage to the r/c receiver (Rx) which in turn provides pulsed voltages to the servos that control the elevator and rudder. The ESC provides pulsed voltages from the battery to the motor according to the Rx signals which are controlled through the pilot's transmitter. The motor draws the most power from the battery system and must be "shut down" when the battery system voltage drops to a pre-determined cut-off voltage. This is required so that if the pilot does not land the plane before the battery system voltage goes too low, that the propulsion motor will turn off but that the servos still have enough power to land the plane safely.

For most r/c racing hobbyists, motors are a type of consumable that are given excessive voltages so that they produce maximum power for short periods of time. It is a common practice in model r/c car racing to replace a vehicle's motor every two races because excessive current has burned the brushes and melted the internal wires. This excessive current is often the deciding factor in whether a car wins or not. The motor typically costs less than a battery system. Racers often "add" one or more additional battery cells in series to the standard battery configuration to gain additional power for a race. In a standard 6 cell r/c racing car configuration, a driver might have a 6 cell battery pack for practicing, a 7 cell pack for hard driving to refine his driving technique during racing, an 8 cell pack for typical racing conditions, and a 9 cell pack to use only when the final race for the championship is at stake. Each battery pack is hard wired to have the full complement of cells, and has a special connector which mates with the connector on the ESC. A racer often has more money expended in a set of batteries than in the racing vehicle itself. The financial difficulty becomes even more pronounced if the racer has three or four different cars that are entered in different events during the day. Each car system needs its own set of batteries for each event.

The same plurality of battery cells exists for r/c boaters, airplane pilots, and helicopter operators. In the r/c flying models, the owner oftentimes has to add additional battery

systems in parallel to the standard configuration of series connected batteries in order to increase the total power available to the system. This is known as an "XsYp" system where X is the number of cells connected in series and Y is the number of "series" configured sets that are finally connected in parallel to give additional power. The need for the "XserialYparallel" system exists because battery cells often come in very small packages. Ideally, huge battery cells should exist so that a single series connected battery system is sufficient. However, motorized gliders often need 30 to 50 battery cells wired in an "XsYp" manner to produce the required power for racing events. Such battery systems can cost many hundreds of dollars to configure. And multiple systems may be needed with increased serial cell counts to produce the excessive voltages needed to win races.

Fig. 2A shows a battery system with six cells 200 connected in series which terminate to a standard connector 201. This is the current state of the art where each of the cells 200 are soldered in a positive to negative daisy-chain manner to increase the voltage, and the output is available at 201 to connect to an ESC which will power the electronics and drive a motor. Fig. 2B shows an additional two cells with a connector 202 that mates with the six cell system in Fig. 2A 201. The connector 203 is the final output of combining the six cell with the two cell subsystem to produce an eight cell system Fig. 2C. The battery system in Fig. 2C can be used in the same airplane, car, boat, or helicopter as shown in Fig. 2A but now produces more power, because of increased voltage, to provide increased performance and win races. There are many r/c devices which only accept six cell systems, and have a special connector 201 which is required to mate with the ESC. In a different airplane, car, boat, or helicopter, an eight cell system may be required. These vehicles typically require a larger capacity connector 203 needed to carry the larger amperage and voltage. In its simplest form, the current invention allows a single battery cell system to be used in either r/c configuration without requiring two separate battery systems for each configuration. One unique advantage of the current invention is that the specialized connectors needed to connect to either an ESC or a motor are integrally part of the design. Connectors are typically of the JST type or the Dean's Ultra connectors which handle relatively large current flows without heating, have a high

resistance to vibrating free during normal operation, and permit the battery systems to be thrown free from a crash of an airplane or rollover of a car. This last feature is essential to stop a propeller from spinning or wheels from rotating so fast that the vehicle motor is destroyed during a mishap.

A second advantage of the current invention is that the wires connecting the six cell to the two cell subsystem allows the final battery configuration to be adjusted in physical layout to match the physical constraints of the model into which the battery system is placed. Fig. 3 illustrates three different configurations of the Fig. 2C system. Configuration 300 shows the additional two cells stacked in the "void" of the Fig. 2A system. This new configuration is often called a "brick" pattern and readily fits into the fuselage and sponsons of most airplanes and boats, respectively. The configuration 301 has the two addition cells oriented to fit behind the six cell set. Such a configuration might be needed in very narrow portions of the fuselage, or when the balance of the airplane or boat needs the batteries distributed over a longer axis. Configuration 302 has the two additional cells stacked upon the thick portion of Fig. 2A battery cells. This configuration is often needed in airplane and helicopter models where the balance point of the vehicle is needed as far forward inside the model as possible. The current invention allows the battery configurations to be adjusted to meet space and balance point requirements for each system into which the cells are installed. Standard battery systems are rigidly held together with tape or heat-shrink tubing and cannot be reconfigured to take new shapes.

A third advantage of the current invention is that repairs of worn-out or damaged battery subsystems are easier to effect. When a battery pack begins to fail to hold a useful charge, typically one or two batteries are defective and the rest of the system cells have 30-40% of their battery life still available. The current invention allows a user to measure the voltages and currents present in both the Fig.2A part of the system separately from the Fig. 2B part of the system. Whichever subsystem is failing can be repaired much easier than traditional r/c battery system where all the cells must be dismantled to perform the tests. This is especially true when there are parallel subsystems involved as will be described next.

Fig. 4 shows a 2s3p system where each subsystem has two serial cells connected together and then three of these subsystems are connected in parallel to form the final battery system. Each of the 2s (two serial) subsystems are identical and have a connector that would allow that subsystem to be used in a vehicle that only needs two serial cells to be functional. By connecting the three subsystems 400, 401, 402 in parallel, they triple the amount of current that the system can deliver to the model. Large electric-powered glider aircraft often have 10s15p NiMh battery cells needed to provide several hundred amperes of sustained power for twenty minutes of motor duration. There are no NiMh cells currently large enough to provide the large current drain, and so a large number of parallel subsystems are needed. Another reason for the parallel subsystems is to allow various packing configurations to fit in the tapering cross-section of the glider's fuselage. The current invention allows all of the parallel subsystems to be identical, and to be used in other aircraft with the proper connector installed. The added advantage is that if one parallel subsystem fails, the replacement of that subsystem is far less expensive than replacing the entire system. Bad crashes in r/c airplanes and cars often destroy only a few batteries located in the immediate impact location. The other batteries usually survive. The current invention allows only a minimal number of subsystems to be replaced or repaired.

Batteries have a specific voltage for each cell type: 1.2 volts for NiCd and NiMh, and 3.7 volts for Lithium. When they are configured in series and parallel systems, problems can arise when they are charged as a group rather than each cell individually. During battery discharge, certain cells will discharge more quickly than others. After many charge-discharge cycles in the vehicle, the battery system can have certain cells that do not get fully recharged because the adjacent cells in the series charge (and discharge) more quickly than others, and cause the charging process to terminate early. This results in some of the series connected cells not having the same voltage and current storage capacity compared to other sets used in a parallel configuration. In the literature this is known as "battery reversal" and "battery memory effect problems". This typically appears only after 5 or more charge-discharge cycles, or when eight or more cells are

connected in series. This can be a serious problem for battery systems used in racing conditions because the reduced power from certain serially connected cells can easily mean the difference between finishing first or finishing third in a race. Over a long period of time, this can render some battery systems unusable.

A modification of the wiring shown in Fig. 2C, which is shown in Fig. 4, permits each cell to be charged independently without disassembling the entire battery system. The wires 403 are connected to each cell's positive terminal. The standard group wires 404 and 405, plus the individual 403 wires, permit any single cell to be charged independently of any other cell. Very small wires can be used for the individual 403 wires since they will carry very small current loads. Every $5^{th}$ to $10^{th}$ charging cycle, a special cable is connected to the battery subsystem which makes use of the individual 403 wires in conjunction with the larger 404 and 405 wires. The battery is first discharged and then re-charged at 1/20 of its specified current capacity. This process typically takes 20 hours and can be accomplished during a day when the vehicle is not being used. The same wiring process that makes up the Fig. 2A and Fig. 2B processes would be used to insure that the individual cell charging feature also has the "XsYp" capabilities of the current invention.

The special cable connects to an electrical interface 406 that uses mechanical relays or electrical switches 407 to connect each cell to the battery charger 408 one at a time to perform the standard discharge followed by the standard charge operation. Once the first individual cell is cycled, the electrical interface then advances to the next battery cell and the process is repeated. This continues until all cells have been independently cycled to bring them up to their full capacity. Special circuitry in the electrical interface box can record the discharge and charge amounts for each cell and display them to the user. Cells that are seriously low in capacity can be identified through this process and replaced. The interface can also identify when a significant number of the individual cells are so reduced in charge capacity that the entire subsystem should be replaced.

The wiring interface for Fig. 4 can either be part of the connector system used to carry the 404 and 405 large capacity wires, or they can be independent connectors that have a small unique connector attached to the covering of either the Fig 2A for Fig. 2B subsystem. This later connector then attaches to the individual 403 wires and can be very light weight. In this configuration, no wires need to extend beyond the battery subsystem outer shell. This reduces system cost and complexity.

Fig. 5 shows a variation on the individual wiring of cells depicted in Fig. 4. In this case, an integrated circuit 510, with an embedded microprocessor and a series of matrix configured FET switches, is attached inside each battery system. A single control line 511 detects a serial coded pulse message from the electronic interface 506 that is attached to the battery charger 408. The programmed message from the serial electronics communication chip 509 tells the integrated circuit inside the battery subsystem which set of FET switches to turn on so that a specific battery cell is either discharged or charged. When the battery charger tells the electronic interface that the operation is complete for that individual cell, the electronic interface sends a new pulse-coded message to the integrated circuit 510 to open the previous set of FET switches and now close a new set corresponding to the next battery cell to be processed. This process would continue until all cells are discharged and then recharged to their full capacity. The advantages of the method in Fig. 5 are that a total of only three wires (404,405,503) need to go from the electronic interface to the battery system. This reduces weight and the chances of broken wire connections. The disadvantage is the added cost of a microprocessor and FET switch matrix inside every battery system. However, in mass production, the method of Fig. 5 will offer the most flexibility since less expensive connectors could be used, and faster charging times could be accomplished through "strobing" effects where multiple cells could be charged at the same time once they are matched to have the same capacity. Also the cost of the integrated circuit and FET matrix would drop rapidly as the volume of battery systems increase.

Figs. 2, 4 and 5 illustrate the method and apparatus used to construct a flexible and extensible battery system for use in r/c model vehicles. All of the battery cells used in

this invention are wired together using solder joints. Mechanical connection of r/c battery systems is not viable because of corrosion, dirt, and weight considerations. The dominant reason why battery systems need a soldered joint is that in car and model airplane applications, stresses of up to five times the acceleration of gravity can be placed on the battery systems during intense maneuvers. If the batteries become electrically separated for even one millisecond, the control systems for steering will typically result in a crash. In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than in a restrictive sense.